U.S. Fish and Wildlife Service

Spring Chinook Salmon Passage at the Leavenworth National Fish Hatchery, 2012

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On the cover*: Structure 2 on Icicle Creek at the Leavenworth National Fish Hatchery. USFWS.*

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Disclaimers

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Abstract- The Leavenworth National Fish Hatchery (LNFH) was constructed and operates under the authority of Section II of the Rivers and Harbors Act of August 30, 1935 (49 Stat. 1028) as partial mitigation for the construction of Grand Coulee Dam. Located on Icicle Creek, the LNFH produces spring Chinook salmon, and has historically used in-stream structures to meet its operational needs. Guided by a U.S. Fish and Wildlife Service Biological Opinion, an Adaptive Management Group was convened to explore means of improving and monitoring fish passage opportunities through these structures in Icicle Creek adjacent to LNFH. Using a DIDSON sonar camera, we were able to monitor the movement of "salmon-sized" fish through one of these structures during the LNFHs' Bloodstock Collection Period. The camera provided timing, direction, and approximate size of the fish passing the structure.

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Introduction

The Leavenworth National Fish Hatchery (LNFH) was constructed and operates under the authority of Section II of the Rivers and Harbors Act of August 30, 1935 (49 Stat. 1028) as partial mitigation for the construction of Grand Coulee Dam. The LNFH is located adjacent to Icicle Creek near the town of Leavenworth in central Washington State (Figure 1). Icicle Creek is a tributary to the Wenatchee River, which flows into the Columbia River, at Wenatchee, Washington. The LNFH is approximately 800 rkm (river-kilometers) from the Pacific Ocean, and upstream of seven hydroelectric dams, all located on the Columbia River (Figure 1).

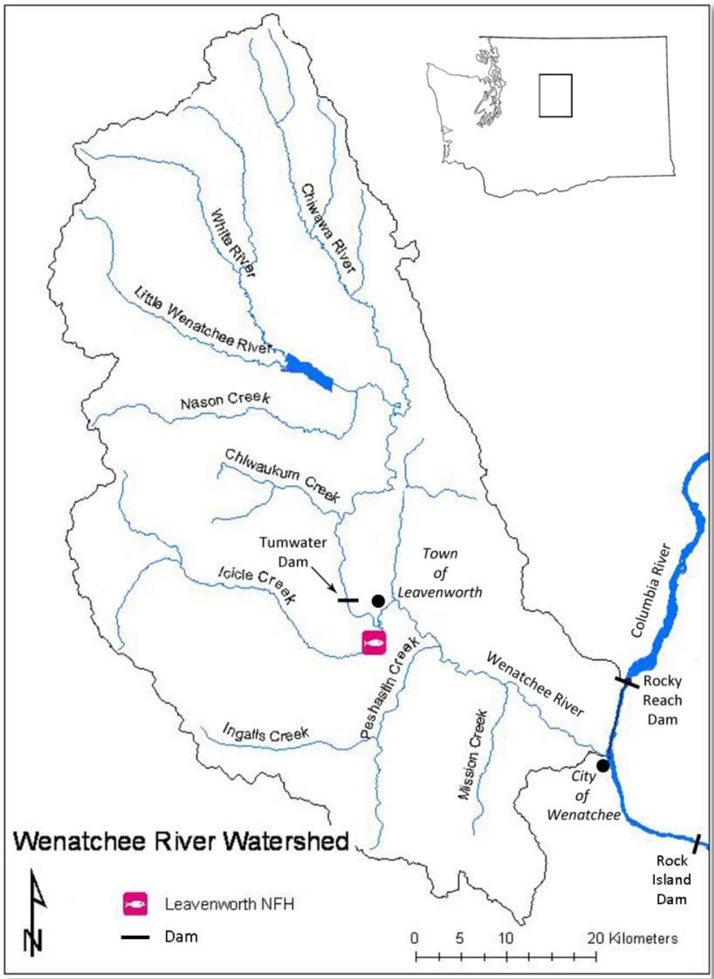

Figure 1. Wenatchee River watershed.

The LNFH is situated on approximately 85 hectares of ponderosa pine/pinegrass forest in the central Cascade mountains (Figure 2). Icicle Creek, a fifth-order stream draining high relief mountains, provides water for hatchery operations as well as the release and collection point for the cultured fish.

Figure 2. The Leavenworth National Fish Hatchery and Icicle Creek.

Historic Operations

The LNFH has produced several trout and salmon species since production began in 1940. Species have included spring and summer/fall Chinook salmon (*Oncorhynchus tshawytscha*), steelhead and rainbow trout (*O. mykiss*), and sockeye salmon (*O. nerka*).

Spring Chinook salmon have been the primary species produced since the hatchery was constructed. From 1940-1943, spring Chinook were collected from upriver-bound stocks captured at Rock Island Dam. Some early imports of spring Chinook salmon from the lower Columbia River (1942) and McKenzie River, Oregon (1941) were part of homing studies, and probably few, if any, contributed to future production. The LNFH has occasionally imported eggs from other Columbia River hatcheries, including Carson, Cowlitz, and Little White Salmon

National Fish Hatcheries. Fish and/or eggs have not been imported to the LNFH since 1985 (Cooper 2006).

LNFH Structure Operation

Since its construction beginning in 1939, the LNFH has operated up to 5 water diversion structures within Icicle Creek to meet its operational needs (Figure 3). These structures were constructed to withdraw water, regulate flows, and collect returning adult salmon. Structure 1 (Hatchery Intake, rkm 7.2) is a low-head dam that acts as a withdraw diversion for both the LNFH and the Cascade Orchards Irrigation Company. A fish ladder was installed there in the early 1990's to improve fish passage. Structure 2 (S2) is a channel spanning dam consisting of 2 radial gates that have the capacity to divert Icicle Creek into the Hatchery Channel, bypassing a 1.6 km section of Icicle Creek known as the Historical Channel (Figure 4). Structures 3 and 4 were weirs used to hold and sort adult salmon within the Historical Channel, and were completely removed in 2003. Structure 5 (S5) is a channel spanning bridge capable of supporting weir pickets. A velocity barrier at the downstream end of the Hatchery Channel prevents adults from swimming up the Hatchery Channel. Fish can, theoretically, move down this barrier, although downstream movement of fish over this barrier is unknown. Structure 2 is of concern with regard to fish passage, and are the focus of this report.

Through 2000, seasonal operation of S2 and S5 impeded fish passage within Icicle Creek (USFWS 2011). In 2001, the LNFH began adaptively managing the structures to improve passage opportunities, and in 2006, an Adaptive Management Group (AMG) was formed to guide the operation of these structures (USFWS 2006).

Current Operations

The LNFH operates a segregated-harvest program producing spring Chinook salmon, and aids in the production of and provides rearing space for coho salmon (*O. kisutch*) for the Yakama Nations' Mid-Columbia Coho Restoration Program. The LNFH also has a few rainbow trout on station for educational purposes.

The number of adult spring Chinook salmon returning to the LNFH from 2002 to 2012 is given in Table 1. The stock utilized by the LNFH is not included in the Endangered Species Act-listed Upper Columbia River spring Chinook salmon Evolutionarily Significant Unit. Genetic analysis indicates that the current broodstock is more closely related to the lower Columbia River stocks than the natural population in the Wenatchee River (Ford et al. 2001). The spring Chinook salmon produced at the LNFH are commonly referred to as "Carson stock", referring to the Carson NFH, where the majority of imported eggs originated.

The Mid-Columbia River Fisheries Resource Office (MCRFRO) conducts monitoring and evaluation of the LNFH spring Chinook salmon program. The MCRFRO is located on USFWS property adjacent to the LNFH, and is responsible for the marking, biological sampling, and special studies with regards to the produced fish.

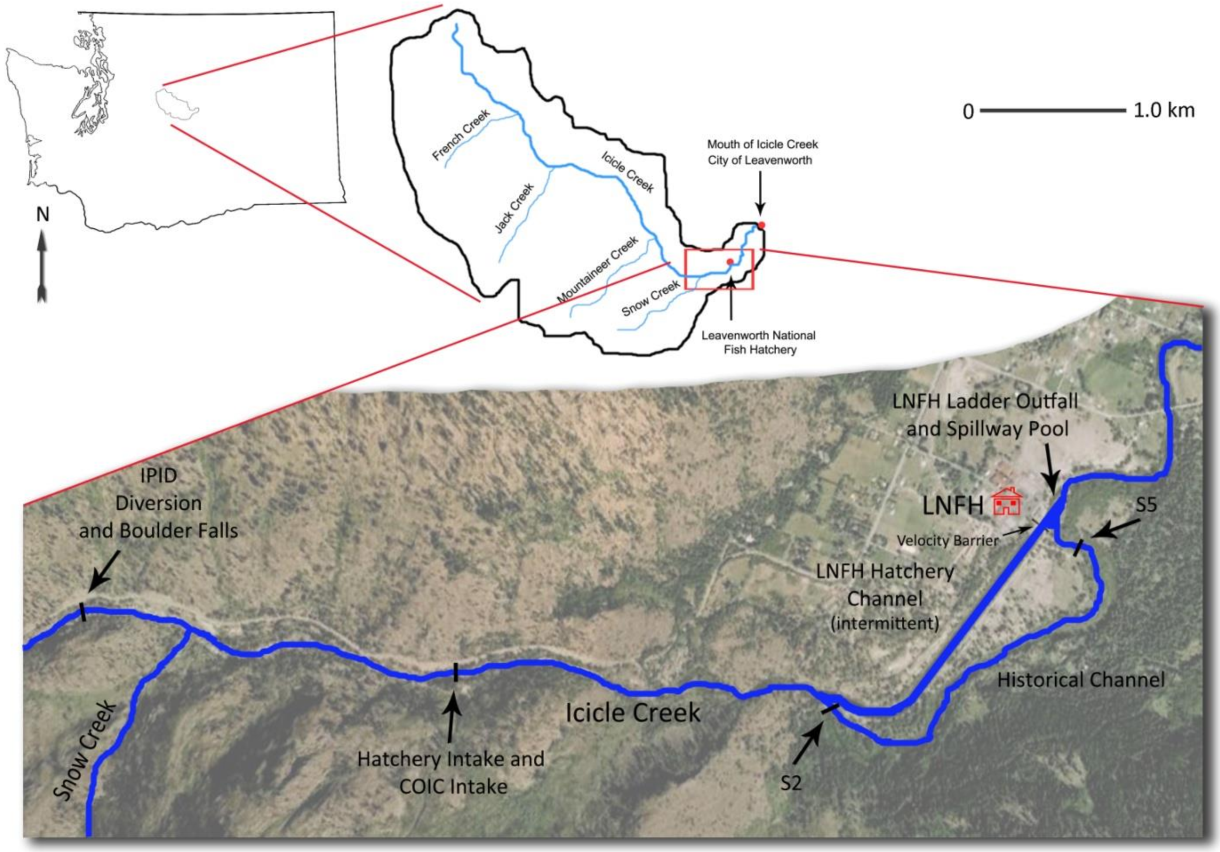

Figure 3. Lower Icicle Creek with LNFH, structures, and Boulder Falls.

Figure 4. Structure 2 (S2) in the open position (left), and the closed position (right). Photos by USFWS.

Table 1. LNFH adult returns, 2002-2012.

Year	LNFH Adult Returns
2002	6459
2003	4825
2004	2307
2005	2560
2006	1957
2007	1708
2008	3229
2009	3045
2010	11366
2011	4970
2012	4037

Salmon Passage at the LNFH

Spring Chinook Salmon

Spring Chinook salmon that enter the Icicle Creek basin are extensively monitored by a variety of entities. When a salmon enters Icicle Creek, it is either harvested by Tribal or sport anglers, captured at the LNFH, or attempts to spawn in the lower 9.1 rkm of the creek. The harvest efforts are monitored by the respective Tribal fisheries agencies and the Washington Department of Fish and Wildlife (WDFW) through creel surveys. All fish captured at the LNFH are sampled by the MCRFRO. Icicle Creek is subject to thorough spawning ground surveys and snorkel surveys conducted by the Chelan County Public Utility District (CCPUD) and the MCRFRO, respectively.

Any salmon that stray out of the Icicle Creek basin have few escapement opportunities. The majority of the spawning habitat available to them exists above Tumwater Dam in the upper Wenatchee River. At Tumwater Dam, differentially-marked LNFH-origin spring Chinook salmon are trapped and transferred to the LNFH. At the current marking rate, 80% of the potentially straying LNFH-origin salmon are prevented from moving onto the upstream spawning grounds.

Given these efforts, accounting for LNFH-origin spring Chinook salmon adults returning to Icicle Creek is possible with a high degree of accuracy.

Monitoring

In 2011, the AMG recommended that S2 and S5 be left in the fully open position during the Broodstock Collection Period (BCP), offering the least impedance to fish passage in over 70 years. While unobstructed passage of native species is a desire of the AMG, the Group also recognized the concern of escapement of spring Chinook salmon from the Tribal fishery and disease transmission originating from adults spawning upstream of the Hatchery Intake. As a result, a condition of operating the Structures in this manner included the monitoring of spring Chinook salmon passage above the LNFH during the BCP, which is defined as May 15 to July 7 (USFWS 2011).

DIDSON Acoustic Camera

The primary method used for monitoring spring Chinook salmon passage at the LNFH is a Dual-frequency Identification SONAR (DIDSON™), manufactured by Sound Metrics Corp. A DIDSON is an acoustic camera that uses SONAR to insonify an underwater region at a high frame rate, allowing for a "video-like" image to be recorded (www.DIDSON.com). The video is recorded in a proprietary file format that can then be viewed with camera-specific software (Figure 5).

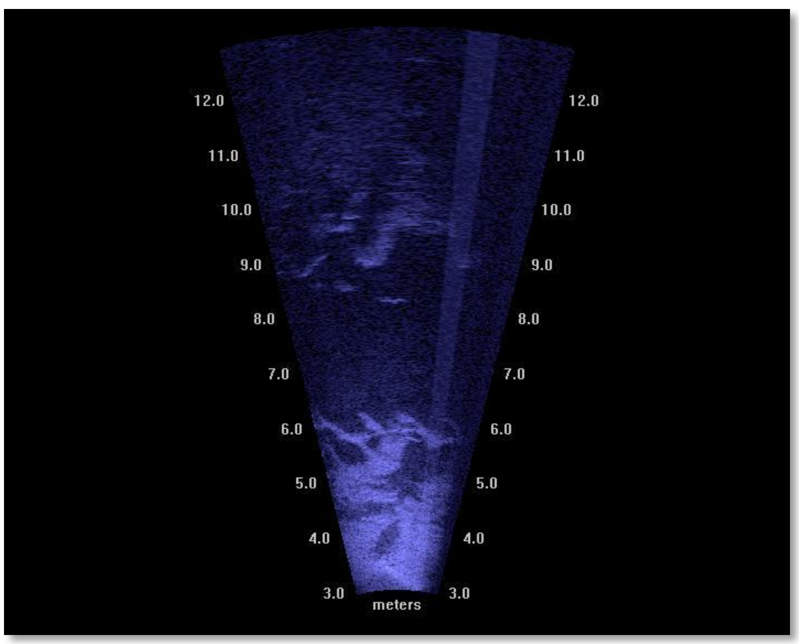

Figure 5. Screenshot of a DIDSON file.

When an object moves through the insonified area, sound waves are reflected back to the camera, creating the image. The software reinterprets the image to appear as it would from above (90^{o} from actual orientation). It is the responsibility of the viewer to determine the nature of the object. In most cases, determining an object as a fish (as opposed to a piece of wood) is easy, with an obvious swimming motion observed.

DIDSON File Viewing

Files are recorded in 1 hr. segments throughout the 24 hr. day, beginning a new file at the start of each hour. The files can then be played at-will, and various software tools can be used to increase the viewing frame rate and eliminate frames with no useful images. These tools allow the viewer to review 1 hour files in as little as a few minutes. Not all files can be reduced equally, and file viewing remains a tedious process.

Fish "Counting"

The DIDSON software has no way of identifying an individual fish that moves into and out of the insonified area. A unique fish could swim into and out of the insonified area multiple times, confounding any attempts to count unique fish. As a result, each viewing instance is more accurately described as a "movement event" rather than a "count". If the movement corridor directs all movement through a defined area (i.e. a "closed" corridor), and a zero count has been established, a "net count", defined as fish movement in one direction, minus fish movement in the opposite direction, can be estimated. This method assumes equal viewability of both upstream and downstream movements. However, fish swimming against the current (upstream) likely move more slowly, and spend more time in the insonified area. This may present a positive bias toward upstream movement events.

In Icicle Creek, the movement corridor being monitored with the DIDSON camera is not closed. A fish *could* swim upstream through the insonified area, and swim downstream through the Hatchery Channel, bypassing camera recording (Figure 3). This would result in a positive bias in upstream counts. However, because of the design of the Hatchery Channel, this effect is assumed to be minimal.

Fish Length

The length of the fish is determined using the softwares' "Mark Fish" tool. With this tool, the fish's length is measured and the direction of the swimming motion can be recorded by drawing a digital line along the axis of the fish in the direction of motion. The lengths of the resulting line, along with the direction, are recorded onto a .txt file that is saved in the desired directory (Figure 6). Burwen et al (2010) found a 90% correlation between DIDSON measured lengths and known lengths, with a Standard Error of 5.76cm. To be conservative, we have reported a +/- 10 cm accuracy with the length measurements taken.

```
Total Fish        =       1
Upstream          =       0
Downstream        =       1
??                =       0

Upstream Motion  = Left to Right
Count  File Name:   C:\Didson Data\FC_CSOT_2011-06-28_210001_P1038.txt
Editor ID          = hall
Intensity          = 77 dB
Threshold          = 11 dB
CSOT Min Cluster   = 100 cm^2
CSOT Min Threshold = 39 dB

Window Start       = 1.67 m
Window End         = 11.67 m

*** Manual Marking (Manual Sizing:  Q = Quality, N = Repeat Count) ***

File  Total  Frame#  Dir   R (m)   Theta   L(cm)   T(cm)    L/T  Aspect    Time      Date      Latitude
-------------------------------------------------------------------------------------------------------------
   1     1     196   Dn    2.63     1.9    87.5     0.0    0.00    13.7  21:04:08  2011-06-28  N  00 d  0.000000 m

*** Source File Key ***

1:      Source File Name:   M:\Hatchery Evaluation Program\LNFH\Didson\CSOT June-28-2011\CSOT_2011-06-28_210001.ddf
        Source File Date:   2011-06-28
        Source File Start:  21:00:14
        Source File End:    21:59:56
```

Figure 6. Example of a DIDSON .txt file output.

Species Identification

In most cases, determining the species of the fish observed is not possible using the DIDSON camera alone. However, with the ability to determine length, combined with other information such as run timing, species identification can be surmised. For the majority of the time period monitored, spring Chinook salmon are the only species in Icicle Creek that exceed 60cm in length. In May and early June, a small run of steelhead is found in Icicle Creek, and migratory sub-adult and adult bull trout (*Salvelinus confluentus*), including some >60cm, use lower Icicle Creek in summer (Hillman et al 2009, Nelson et al 2011).

Data Entry and Reporting

Movement events, time, date, and direction of motion are first recorded on a bench sheet, and then entered into a Microsoft Access™ database for analysis. Length file outputs (.txt's) are saved with the original DIDSON file. An informal, weekly update is sent to the AMG at the end of each week, allowing the AMG to make in-season management decisions regarding S2 and S5 operation.

Site Selection

The DIDSON camera insonifies a field at 30^0 horizontal and 14^0 vertical, for up to 20 meters. The camera must be tethered to a personal computer located within 500ft. Both the camera and the personal computer must be continuously powered throughout the monitoring period.   The DIDSON camera is also very expensive and must be protected from objective hazards. These specifications require careful site selection to maximize data quality and minimize risk. In 2010, numerous sites were considered for DIDSON deployment. The camera was deployed for several weeks at a site approximately 200m upstream of S5. This site provided an inadequate viewing area, poor solar performance, and exposure to debris.

In late 2010, a site on the upstream side of S2 was identified to have many of the characteristics needed for successful monitoring (Figure 7). This site provided a good viewing window because the nature of S2 funnels fish into the viewing area. It also has the required solar exposure and complete protection for the camera. This site has the disadvantage of limiting the insonified area to the bottom 1m (approximately) of the water column. Because salmon are most likely to swim near the bottom of the channel while negotiating S2, the effects of this limitation is thought to be minimal. This site was used for the entire 2012 monitoring season.

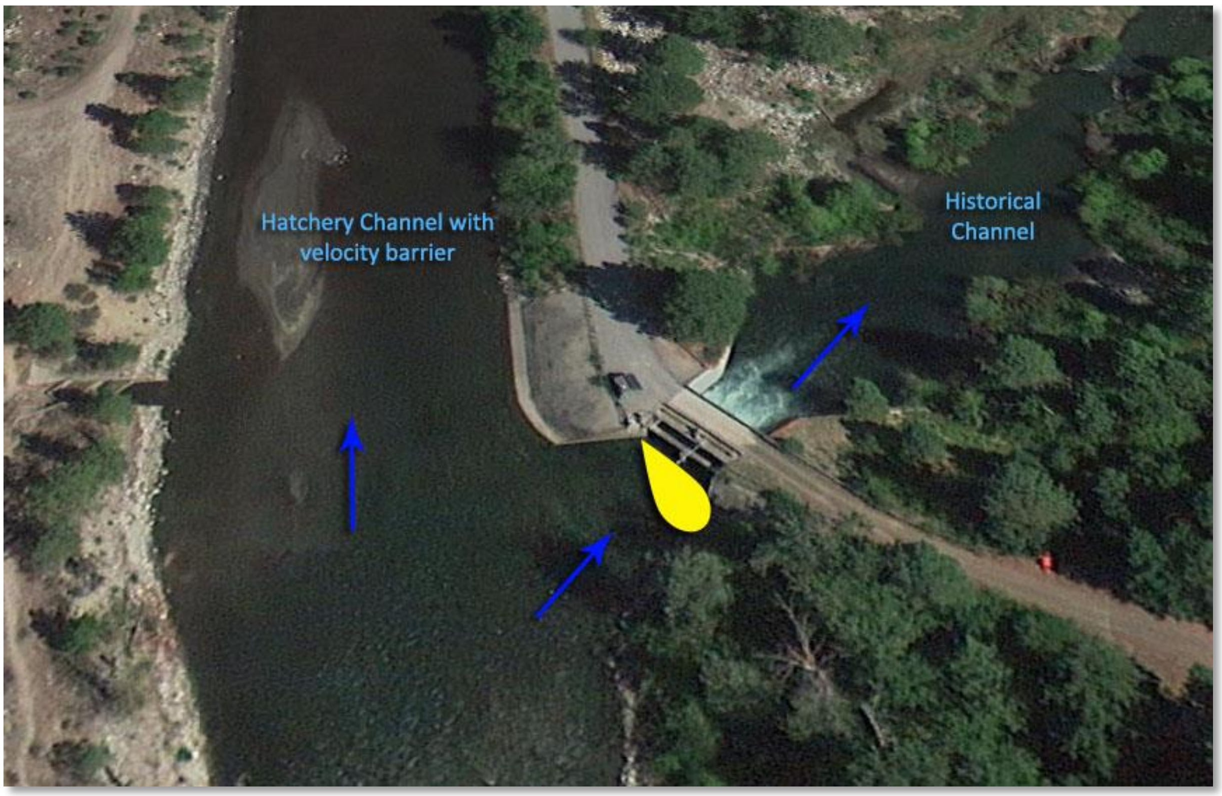

Figure 7. Aerial photo of S2 with insonified area in yellow. Courtesy of Google Maps.

Deployment Dates

The 2011 Biological Opinion requires the monitoring of spring Chinook salmon passage above the LNFH during the BCP. In 2012, monitoring occurred until July 27, with only July 7 and 8 having no monitoring.

Icicle Creek Conditions

Icicle Creek Discharge

The Icicle Creek basin experienced a cool and wet spring followed by an average summer in 2012 (Hall 2013). Icicle Creek discharge was protracted throughout the late spring and into the summer months (Figure 8). Total Icicle Creek discharge was measured at a Washington Department of Ecology station gauge (ID# 45B070), and S2 discharge is calculated from total discharge measurements (M. Lindenberg, pers. comm.). The S2 discharge (Q^{S2}) is calculated from the total discharge of Icicle Creek (Q^{total}) using the following polynomial regression:

$$Q^{S2} = -0.0001(Q^{total(2)}) + 0.9426(Q^{total})$$

Below 300 cfs (approx.), all of the discharge of Icicle Creek flows through S2 and the Historical Channel. From 300 to 1000cfs, a portion of Icicle Creek discharge fills the Hatchery Canal. Above 1000 cfs, the portion of Icicle Creek within the Hatchery Canal begins to spill over its velocity barrier, reconnecting with the Historical Channel immediately downstream.

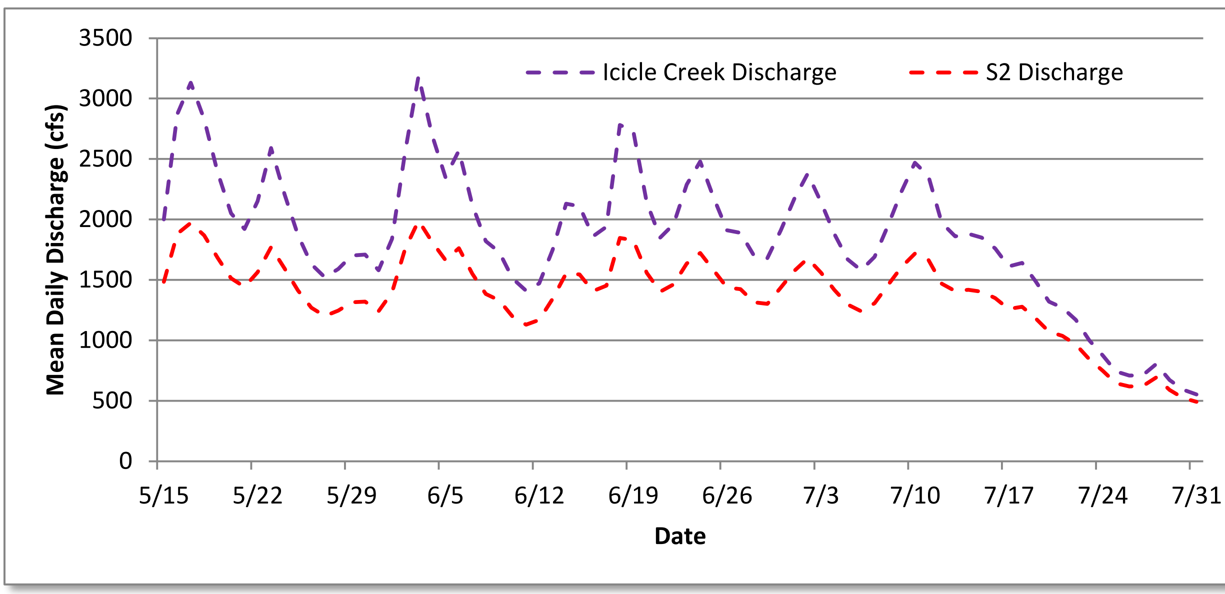

Figure 8. Mean daily Icicle Creek discharge and calculated discharge through S2 in 2012.

DIDSON Monitoring Results

Broodstock Collections Period Totals

During the BCP (May 15 to July 7), 88 upstream movement events occurred, and 36 downstream movement events occurred, resulting in a net of 52 upstream movement events (Figure 9).

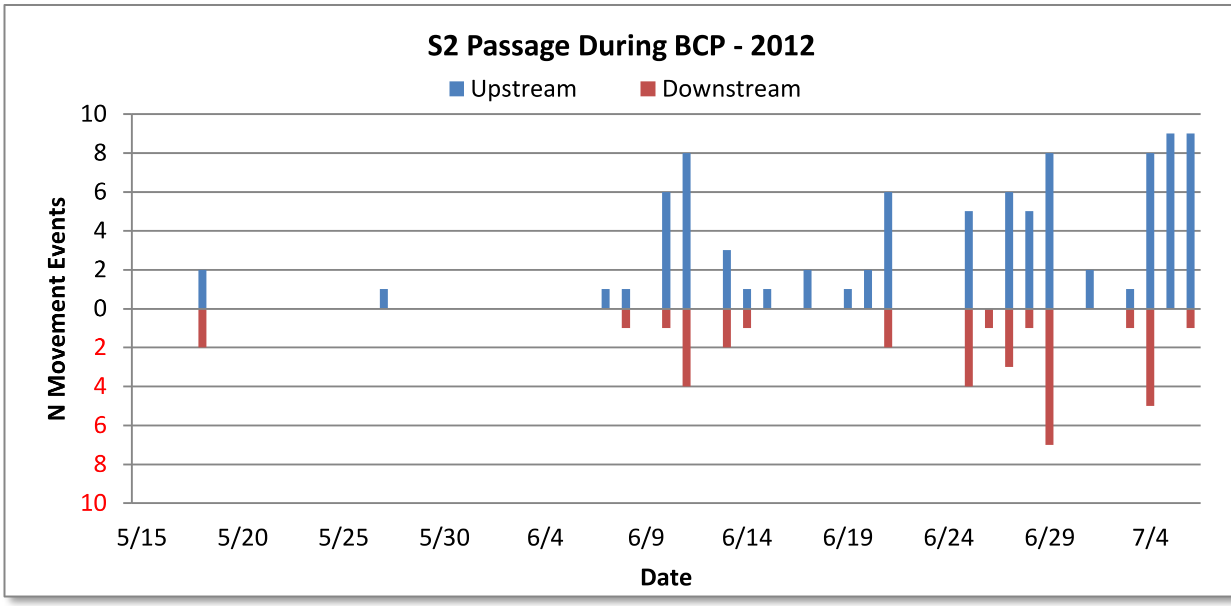

Figure 9. Movement events at S2 during the BCP, 2012.

Season Totals

Monitoring of fish passage at S2 continued through July 27. For the entire 2012 monitoring season, 393 upstream movement events occurred, and 106 downstream movement events occurred, resulting in a net of 287 upstream movement events (Figure 10).

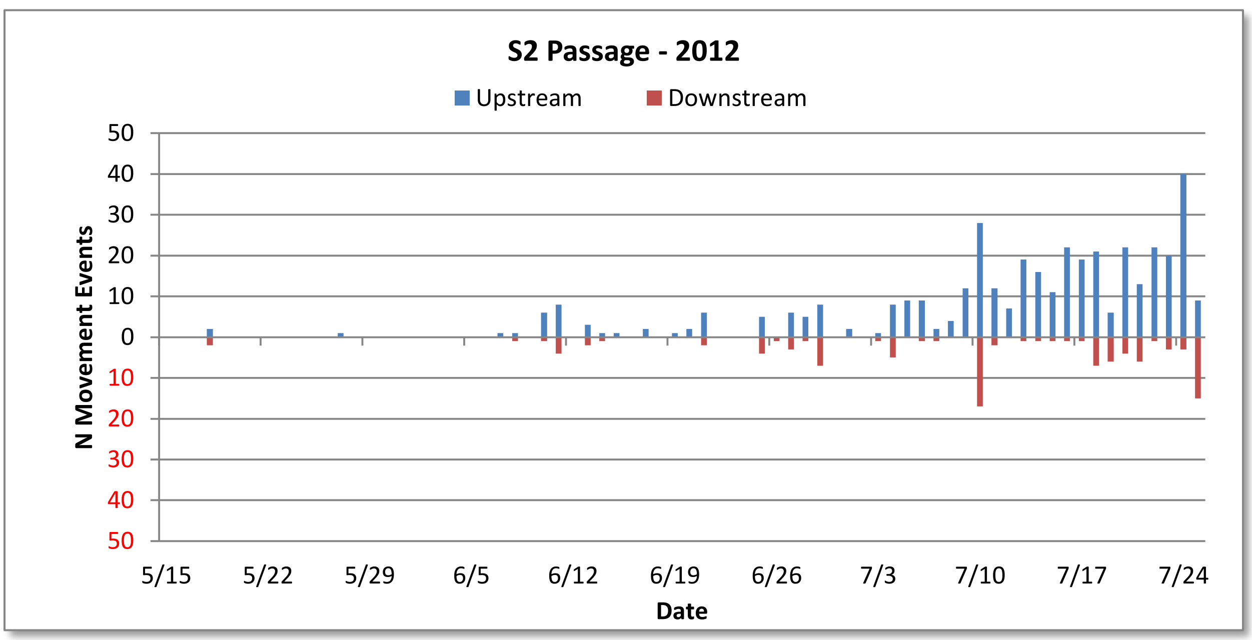

Figure 10. Movement events at S2 during the entire 2012 monitoring season.

Lengths

Length measurements were taken on 92 of the 124 movement events during the BCP. Of these, 1 fish (1%) were measured to be <60 cm. This falls within the range of 3-year old ("jack") salmon, but is also within the range of resident fish known to be present in Icicle Creek. The remaining 91 fish were of a size commensurate with adult (4+year old) salmon, anadromous steelhead, or adult bull trout.

During the entire 2012 season, length measurements were taken on 460 movement events. Of these, 16 (3.4%) were measured to be <60cm. The length/frequency distribution for the entire 2012 season is shown in Figure 11. The temporal occurrence of a fish of a given length is shown in Figure 12.

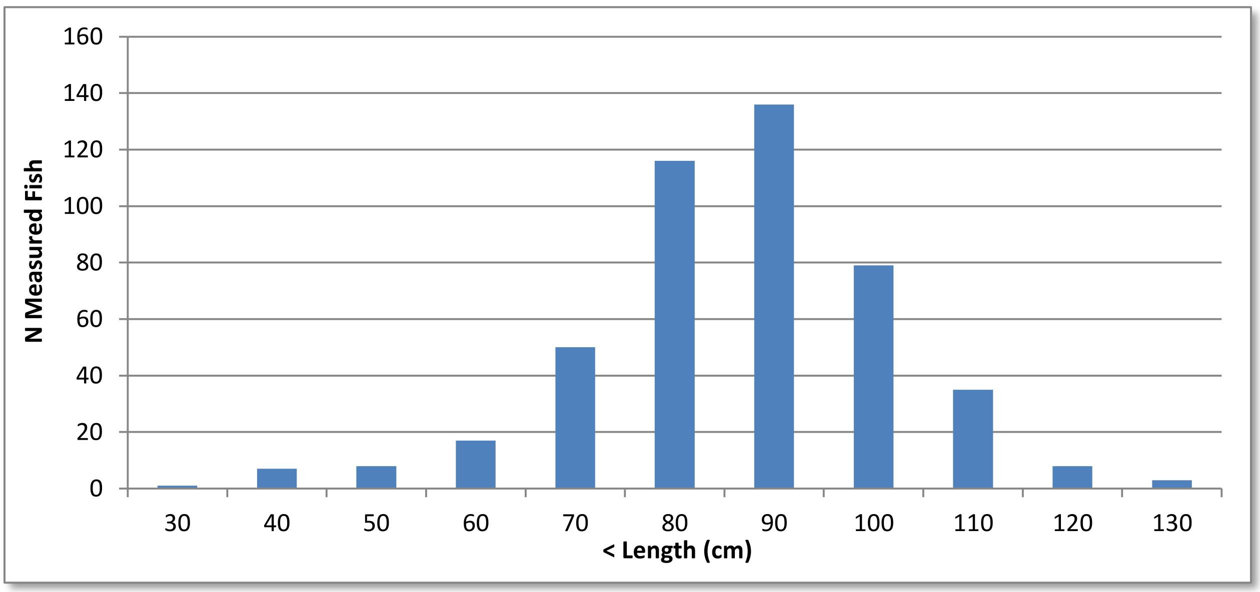

Figure 11. Length/frequency distribution of fish measured during the entire 2012 monitoring season.

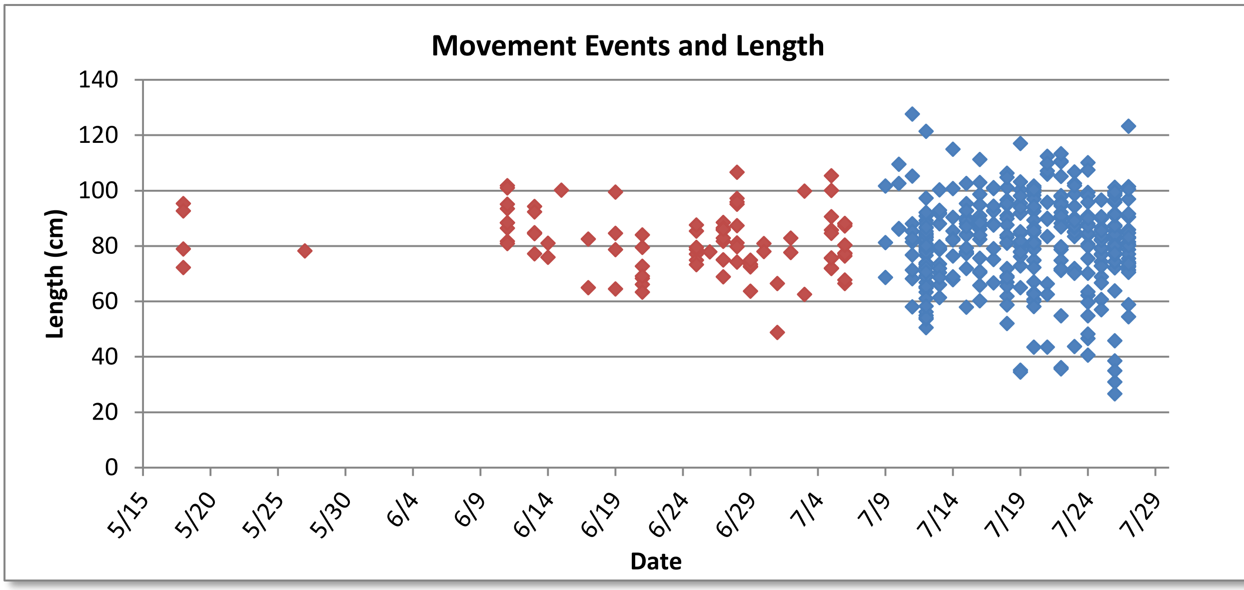

Figure 12. Plot of movement events and their corresponding length over the entire 2012 monitoring season, with red indicating events during the BCP.

Discussion

Broodstock Collection Period

In 2012, 124 movement events were observed during the BCP, with 88 upstream and 36 downstream, resulting in a net of 52 upstream movement events. This is fewer overall movement events then occurred in 2011 (124 vs. 224), but more net upstream events (52 vs. 16). The movement events in 2012 were less balanced between the upstream and downstream direction resulting in a larger accumulation of net upstream movements (Hall 2012).

The 52 net upstream movement events accumulated slowly until mid-June, then increased steadily until July 4. In the final 3 days of the BCP, net upstream movement increased dramatically, accounting for nearly 40% of the cumulative total. This pattern of movement is slightly different than that of the 2011 monitoring season, where net upstream movement began to accumulate earlier and progressed more slowly (Figure 13, Hall 2012).

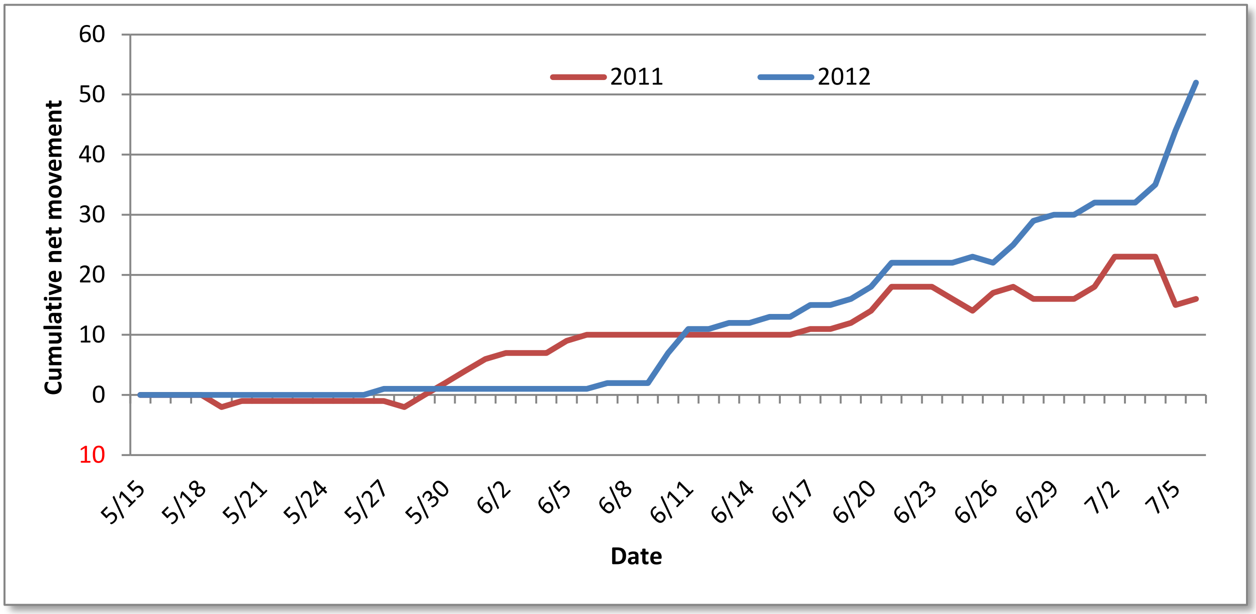

Figure 133. Cumulative net movement events during the BCP, 2011 and 2012 (2011 data from Hall 2012).

Season Totals

After the BCP, net upstream movement events continued to accumulate at a high rate until monitoring ceased on July 27 (Figure 19). At the end of the monitoring season, there were 393 upstream movement events, and 106 downstream movement events, with a net upstream movement of the 287 events. Of these 287 net upstream events, 83% of them occurred after the end of the BCP.

When compared to the same time period in 2011, movement events in 2012 began to accumulate slightly later, however once begun, they accumulated at a higher rate (Figure 14). At the end of the 2012 monitoring season, more upstream movement events had accumulated than during the same period in 2011 (287 vs. 190).

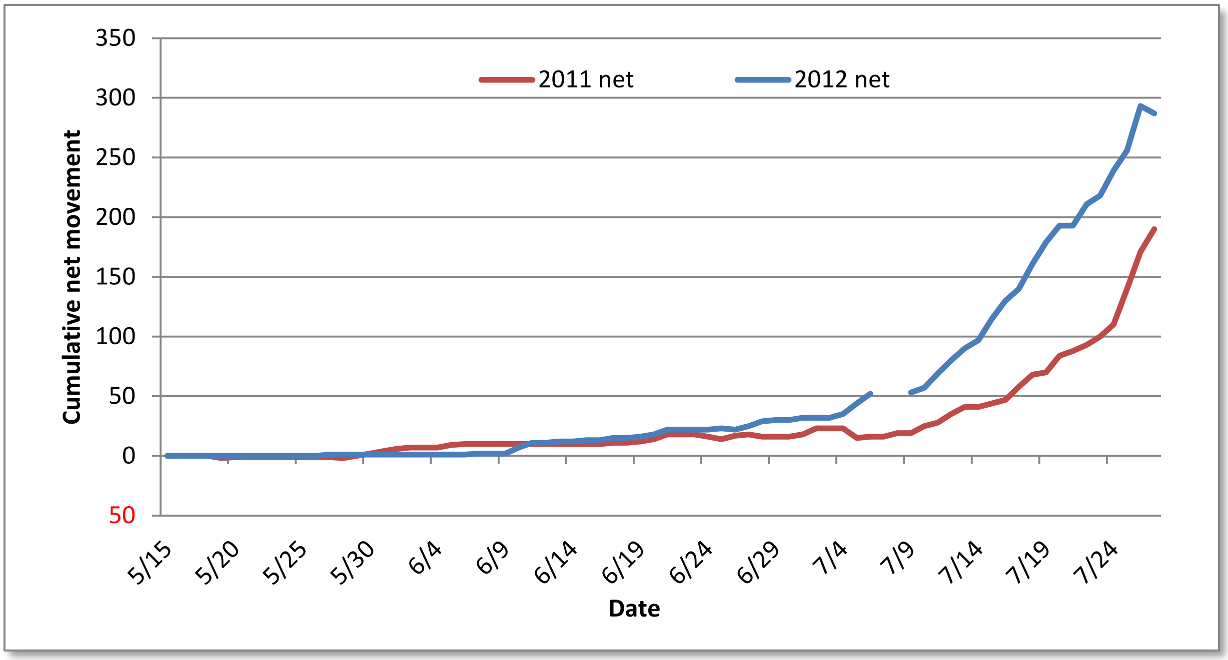

Figure 14. Cumulative movement events through July 27, 2011 and 2012 (2011 data from Hall 2012).

Spring Chinook Salmon Escapement

Multiple methods can be used to estimate the total number of spring Chinook salmon using the limited habitats of Icicle Creek. Using PIT tag data, we can calculate that the 64 PIT-tagged LNFH origin spring Chinook salmon that passed Rock Island Dam (on the Columbia River) is estimated to represent 5,572 fish (does not include 2YO "minijacks", Columbia River DART). Nearly all of these fish are destined for Icicle Creek, with no harvest in the Columbia or Wenatchee Rivers. Another model, using Bonneville Dam counts, historic adult returns, and harvest rates, predicted 7,668 adult spring Chinook salmon would enter Icicle Creek (Cooper pers. com.).

From the estimated 5,572 to 7,668 spring Chinook salmon using Icicle Creek in 2012, an estimated 971 were harvested in the Icicle Creek sport harvest, an estimated 1425 were harvested in the Icicle Creek Tribal harvest, and 4,037 were collected at the LNFH adult ladder trap (Maitland pers. com., Dick pers. com., Table 3).

Table 2. Estimates of accounting metrics for Icicle Creek adult spring Chinook salmon returns.

Year	Estimated Icicle Creek Sport Harvest	Estimated Icicle Creek Tribal Harvest	LNFH Adult Ladder Trap	Estimated Total Accounted For
2012	971	1,425	4,037	6,433

To estimate how many spring Chinook salmon remained in Icicle Creek after the BCP, two independent surveys can be examined. First, the CCPUD conducts spawning ground surveys for spring Chinook salmon in Icicle Creek in August and September each year. In 2012, 34 redds were surveyed and 5 carcasses were sampled above S2 (Keller pers. com., Table 4). The number of redds in Icicle Creek is multiplied by the female-to-male ratio of the adult returns to the LNFH, resulting in an estimated number of adults responsible for a given number of redds (Hillman et al 2011). For 2012, 34 redds multiplied by a female-to-male ratio of 1.86 estimates 63 adult spring Chinook salmon building redds above S2.

Table 3. Spring Chinook salmon redds in Icicle Creek above S2.

Year	River	Redds Above S2
2006	Icicle	0
2007	Icicle	2
2008	Icicle	34
2009	Icicle	9
2010	Icicle	27
2011	Icicle	19
2012	Icicle	34

Second, the MCRFRO annually conducts a thorough snorkel survey of the entirety of Icicle Creek downstream of the barrier to anadromy at rkm 9.1. In 2012, this survey occurred on August 9, and 131 adult spring Chinook salmon were encountered in the entire Icicle Creek, with 73 of these occurring above S2 (Hall internal memo 2012, Table 5).

Table 4. Estimated spring Chinook salmon in Icicle Creek above S2, based on snorkel surveys. Includes live fish and carcasses.

Year	River	SCS Above S2
2006	Icicle	36
2007	Icicle	24
2008	Icicle	202
2009	Icicle	135
2010	Icicle	146
2011	Icicle	17
2012	Icicle	73

In 2012, estimates of Icicle Creek spring Chinook salmon run size ranged from 5,572 to 7,668 fish. An estimated 6,433 fish can be accounted for through hatchery returns and harvest creels.

Spawning above S2 involved an estimated 63 (based on spawning ground surveys) to 73 (based on snorkel surveys) adult fish.

Acknowledgments

The author would like to thank the technicians that spent countless hours analyzing files and entering data. As Peter Galbreath noted in 2005, "Reviewing DIDSON files is a tiresome and boring task." Also appreciated is the logistical support of the LNFH maintenance staff.

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